AIR FORCE NICKEL-HYDROGEN FLIGHT EXPERIMENT

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The Air Force experiment data has been presented before, and because of the rush in the program which necessitated us using existing nickel-cadmium battery technology and components, I think the time from inception of the program to launch was about 18 months.

It doesn't really incorporate the current technology that is available today. As I go over this, I will probably pass over some of these vugraphs very quickly until we get to the summary of the data at the end.

What I think is important is to look at it from the standpoint that this was not a really good design. It had a lot of bad points. But the battery forgave any design problems that cropped up.

The program intent was, of course, to gain some actual flight experience on nickel hydrogen. It is supposed to be the first one launched, but I think the NTS-2 and the Air Force launched just about the same time.

The program was under the direction of Wright Patterson Air Force Base. Eagle Picher was the prime contractor for the first time I guess in the history of the business, and Lockheed Missile and Space Company was the subcontractor.

The mission wasn't of a long duration. It was about 8 months. It was launched on the Air Force low-Earth orbit satellite as an experiment in one of the pilots.

(Figure 6-34)

I was going to say the cell on your right, but now I am going to say the cell on the top. It is the actual Air Force cell, and it has a rather narrow cover design. It uses an Inconel 625 pressure vessel. The little capsule in there is the module for attachment of the strain gauge.

Internally, it features what is referred to as the Air Force pineapple stack design. However, it doesn't have the most current technology, and basically the recirculation mechanism is in wall-wick configuration.

I might mention the smaller cell just below it. That was the cell manufactured for the Navy NTS-2 program, that basically features the COMSAT laboratory design technology.

Actually the cell we are manufacturing now for Ford looks very much like that. The difference is about a quarter inch shorter.

(Figure 6-35)

With respect to cell design features – this just touches upon Hughes' design characteristics. Fifty-five ampere-hour electrochemically impregnated nickel electrodes. This was manufactured on the Bell impregnation line which was still in operation at that time, in Joplin.

Teflonated platinum catalytic electrodes and the separator were EPI reconstituted asbestos. The gas spacer – I think that's an error – was actually switched over in the final cell designs to a Vexar polypropylene material. The cell casing is hydroformed Inconel 625, dual plastic seals.

(Figure 6-36)

The cell acceptance testing was pretty much what you see in nickel cad: some four 100-percent cycles, charge retention, electrolyte leakage, fuel cycle test, electrolyte leakage.

(Figure 6-37)

With respect to the battery itself – this is view of the battery – it is upside down. Actually, this is the way it was mounted in the spacecraft. It is an aluminum cached configuration. The heater blanket is attached on the bottom of the system. That's an area that also looked into space for coolant control.

(Figure 6-38)

Here is the same battery with cells mounted into it on the vibration going through qualification. A lower portion there, the copper colored component just for protection. That didn't actually fly in orbit. It wasn't part of the battery and did not fly on the mission.

The battery design features are shown in the next vugraph.

(Figure 6-39)

The number of cells was 21. It turned out the same approximate voltage as the 22-cell nickel-cadmium battery.

We monitored each cell voltage, one battery voltage. Current monitoring bipolar electromatic sensor. Again, the technology on these components are straight off the Eagle Picher nickel-cadmium battery.

The number of thermistors is 21. Each cell two batteries, two in the battery. For pressure monitoring, we had strain gauges on every cell. The heater is redundant; of course, redundant controllers. The total battery weight was 110 pounds. Again this was not intended to optimize the system with respect to weight.

(Figure 6-40)

I believe this is the acceptance test. Again, it is very similar to what you expect to do on nickel-cadmium battery dielectric thermistor insulation, current sensor, some capacity cycling, dimensional pressure, inert gravity.

May I have the next slide which shows the qualifications.

(Figure 6-41)

Again, this is patterned after nickel cadmium. Acceleration thermal random, sinusoidal, mechanical pyrotechnic, thermal vacuum cycling. Then, there is this special thermal vacuum because it turned out to be a thermal design in the system. We didn't have a variable window looking out into space, and there was real concern that the battery would get too cold after it was launched before we would go into operation.

It turned out it was able to endure this low-temperature exposure without damage.

(Figure 6-42)

This is a diagram of how the battery was mounted on the pallet. Three major components include the battery, control assembly, and the variable load bank.

The technology I considered primitive. The battery was controlled by a single-level voltage geared to bring the voltage cell to 90-percent state of charge at a pressure of about 500 psig. There was no other means of changing anything on the battery if it proved necessary.

The thermal control designs were all fixed. We couldn't make any changes there except with the heaters. We could turn those off and on more frequently or as required.

(Figure 6-43)

As I indicated, the battery flew as an experiment, so we were restricted; limited in our use of the system based upon the power that was left over after the primary mission was served. So we didn't get a lot of cycles on the battery. However, the way it was used was for nickel cadmium. It created a serious problem because we had to go into a number of orbits to get the battery back up to charge, and that would vary with each cycle.

In the nickel cadmium, the power measurement people would have been completely lost with respect to where the battery was. However, with the pressure monitoring devices on the battery, they knew at all times the exact state of charge of the system.

The 1733, 7-percent DOD cycles were accumulated when the battery was actually supplying power to the primary mission. The 50-percent DOD cycles that were accumulated were accumulated using variable load bank. That was part of the experiment. Of course, 100-percent DOD cycle was used when we were using the variable load bank.

Four of the loads that were available, 10, 20, 30, and 40, could be used separately or just combined as you see in the last column there.

Maximum discharge rate was 75 ampere-hours and the 1.5 C rate.

Over on the last two columns, you can see how close the predicted capacity versus the measured capacity package. As you can see for the 10 ampere and the 20 ampere rate, what we predicted and measured were very close. Once you get into higher discharge rates, they start to drift apart.

What is going on here is that at these higher rates, the battery is hitting the cutoff voltage sooner. If you took it on down to a lower discharge rate, that brought those two predicted and measured pretty much back together again.

With respect to the thermal cycling of the system, as you see, the deltas were for the 20, 40, and 75-ampere hour rates. What might be of interest here is what actually happened. There were three batteries manufactured, and some of those underwent testing on the ground. The mechanical model was tested at Lockheed.

Again, although the designs certainly are not optimum, the way it was used was certainly not under the best of conditions. But the mechanical model at Lockheed, I understand now has gone through 6000 cycles at around 60-percent DOD and still seems to be performing very well.

I understand the thermal model battery is at Wright Patterson. I have no information on what testing was done on that.

Again, a point I want to make is that although it is certainly not elaborate testing of the system, we did get very good data. We are satisfied with the results of the program. We didn't see any incipient problems with the use of nickel hydrogen in space, and it pretty much followed the preflight predictions. Overall I think we are very satisfied with this program.

DISCUSSION

DUNLOP: What was that cutoff voltage?

MILLER: I think the cutoff voltage was around 149. I'd have to check that for sure.

DUNLOP: How did that limit your discharge capacity?

MILLER: It didn't. That was just the charge cutoff. They fixed one level charge cutoff point.

DUNLOP: When you showed a 75-ampere discharge rate, you showed the capacity dropping down to 34 ampere-hours. I guess I didn't understand that point.

MILLER: That was just the cutoff on the voltage which I think was also established at about 1.1 volts per cell. That circuit undervoltage production could be disabled to allow it to go down.

I mentioned also the battery was reversed twice. Once intentionally and once in error during the mission, and we haven't suffered any damage.

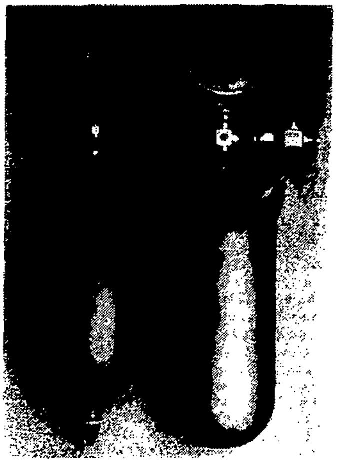

Figure 6-34

RNH-50-9

CYLINDRICAL CELL DESIGN FEATURES

CAPACITY	55 AH
CATHODE	ELECTROCHEMICALLY IMPREGNATED NICKEL ELECTRODE
ANODE	TEFLONATED PLATINUM CATALYTIC ELECTRODE
SEPARATOR	EPI RECONSTITUTED ASBESTOS
GAS SPACER	WOVEN TEFLON
CELL CASE	HYDROFORMED INCONEL 625
TERMINAL SEAL	DUAL-PLASTIC COMPRESSION

Figure 6-35

CELL ACCEPTANCE TESTS

GAS LEAKAGE TEST	10^{-8} cc/sec @ 250 PSIG		
CAPACITY TEST @ C/2	CHARGE RATE	TEMP	CAPACITY
	12.5 Amp	68°F	48.8 AH
	3.0 Amp	68°F	51.2 AH
	12.5 Amp	45°F	51.2 AH
	3.0 Amp	45°F	52.5 AH
DISCHARGE FROM 1.0 TO 0.0 VOLTS	21.2 PSIG		
CHARGE RETENTION TEST	39.2 AH AFTER 48 HOURS		
ELECTROLYTE LEAKAGE TEST	NONE		
CYCLE TEST	52.9 AH @ 6TH CYCLE		
ELECTROLYTE LEAKAGE TEST	NONE		

Figure 6-36

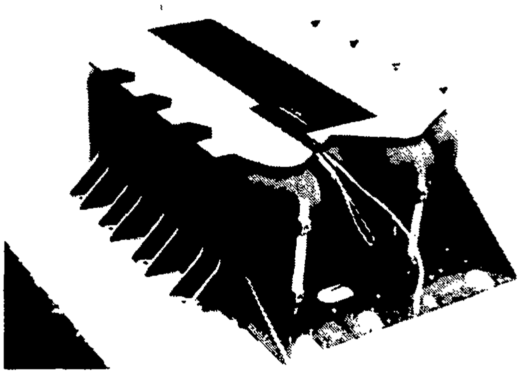

Figure 6-37

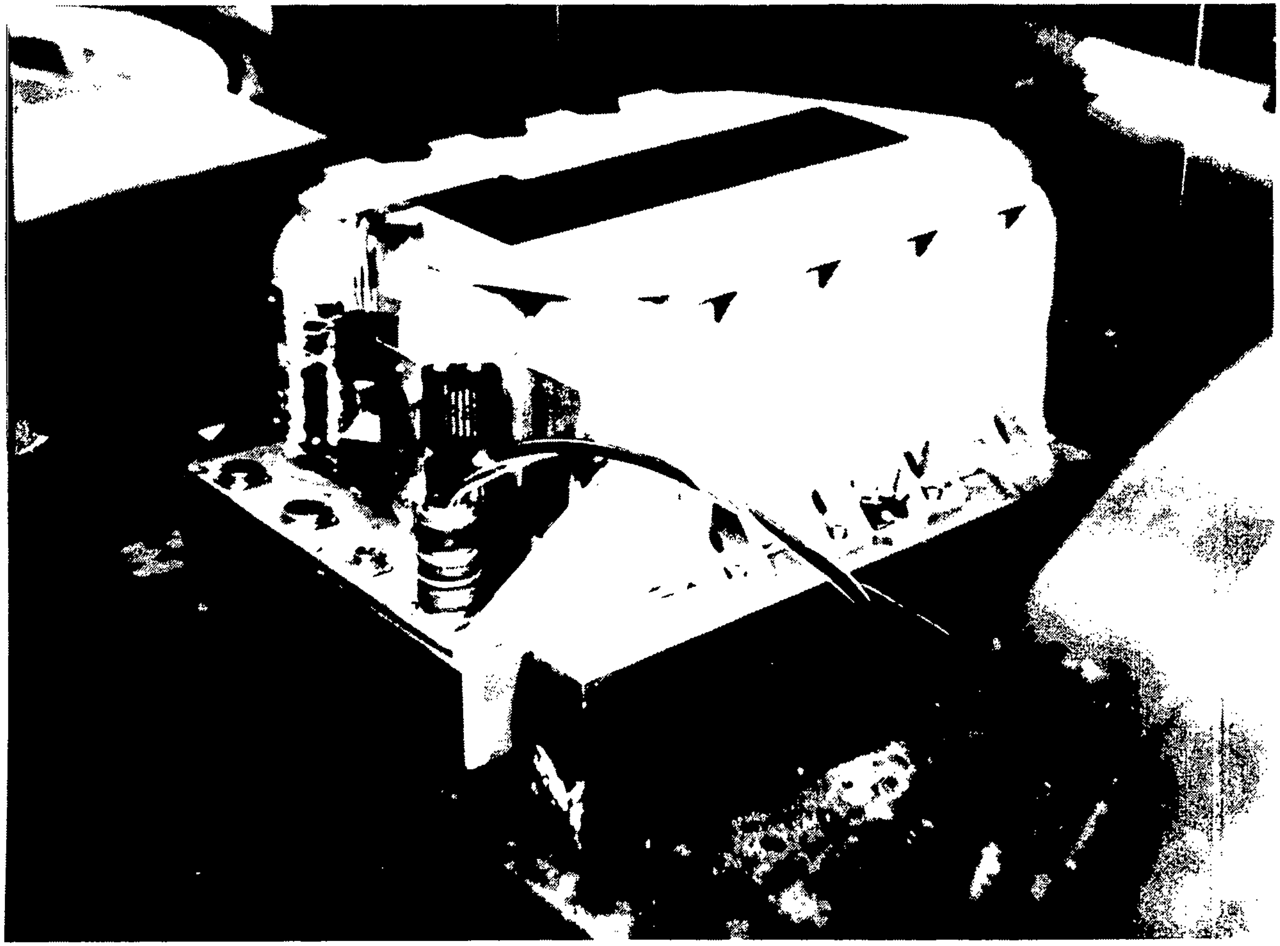

Figure 6-38

SAR-10005

BATTERY DESIGN FEATURES

- NO. OF CELLS	- 21
- BATTERY STRUCTURE	- INVESTMENT CASTING ALUMINUM A-356-T61 ALLOY
- VOLTAGE MONITORS	- 21 INDIVIDUAL CELLS 1 BATTERY
- CURRENT MONITOR	- B1 POLAR ELECTROMAGNETIC SENSOR (20 AMPS CHARGE - 50 AMPS DISCHARGE)
- TEMPERATURE MONITORS	- THERMISTORS (21 CELLS - 2 BATTERY)
- PRESSURE MONITORS	- STRAIN GAGE - 21 CELLS
- HEATERS	- REDUNDANT PHOTOETCHED
- HEATER CONTROLLERS	- REDUNDANT SOLID STATE
- BATTERY WEIGHT	- 110 LB

Figure 6-39

BATTERY ACCEPTANCE TESTS

VISUAL INSPECTION	
WEIGHT CHECK	110.0 LBS
DIELECTRIC TEST	10-20 MEGOHMS @ 250 VDC
THERMISTOR TEST @ 77°F AND 40°F	
INSULATION RESISTANCE TEST	50 MEGOHMS @ 50 VDC
STRAY VOLTAGE CHECK	LESS THAN .05 VOLTS
CURRENT SENSOR TEST @ 12.5 AMPS CHARGE, ZERO AND 25.0 AMPS DISCHARGE	
TEMPERATURE SENSOR TEST @ 40 AND 77°F; EXCITATION VOLTAGE 24, 28.5 AND 33 VDC	
CAPACITY TEST @ C/2	68°F - 50.0 AH 40°F - 51.7 AH
HEATER TEST	PRIMARY HEATER ON - 41°F BACK-UP HEATER ON - 36°F BACK-UP HEATER OFF - 38.6°F PRIMARY HEATER OFF - 44.3°F
DIMENSIONAL CHECK	
PRESSURE SENSOR CALIBRATION CHECK	
C.G. DETERMINATION	
INSTRUMENTATION & HEATER BUS POWER CONSUMPTION CHECK	

Figure 6-40

BATTERY QUALIFICATION TESTS

ACCEPTANCE TESTS	
ACCELERATION TEST	15 G FOR 5 MINUTES (3 AXES)
THERMAL SHOCK	$-20^{\circ}F$ TO $+115^{\circ}F$
RANDOM VIBRATION	12 G RMS FOR 5 MINUTES (3 AXES) 0.1 G^2/Hz
SINUSOIDAL VIBRATION	7.5 G FOR 25 MINUTES (3 AXES)
MECHANICAL SHOCK	30 G; 1/2 SINE WAVE; 11 MS
PYROTECHNIC SHOCK	2600 G PEAK ACCELERATION; 200 - 10^{-4} Hz
THERMAL-VAC PERFORMANCE TEST	10^{-4} TORR @ 32°, 59° AND $86^{\circ}F$ CHARGE / DISCHARGE 5.0 AMPS / 50.0 AMPS 25.0 AMPS / 25.0 AMPS 50.0 AMPS / 5.0 AMPS
THERMAL-VAC CYCLE TEST	10^{-4} TORR @ $40^{\circ}F$ 30.0 AMP CHARGE FOR 55 MINUTES 42.8 AMP DISCHARGE FOR 35 MINUTES 32 SIMULATED ORBITS, 50% DOD
SPECIAL THERMAL-VAC TESTS	INSTRUMENTATION POWER DISSIPATION HEATER CALIBRATION SPECIFIC HEAT MEASUREMENT CHARGE EFFICIENCY VS. TEMPERATURE STATE-OF-CHARGE CHARGE CURRENT SIMULATED 90 MINUTE ORBIT CYCLES

Figure 6-41

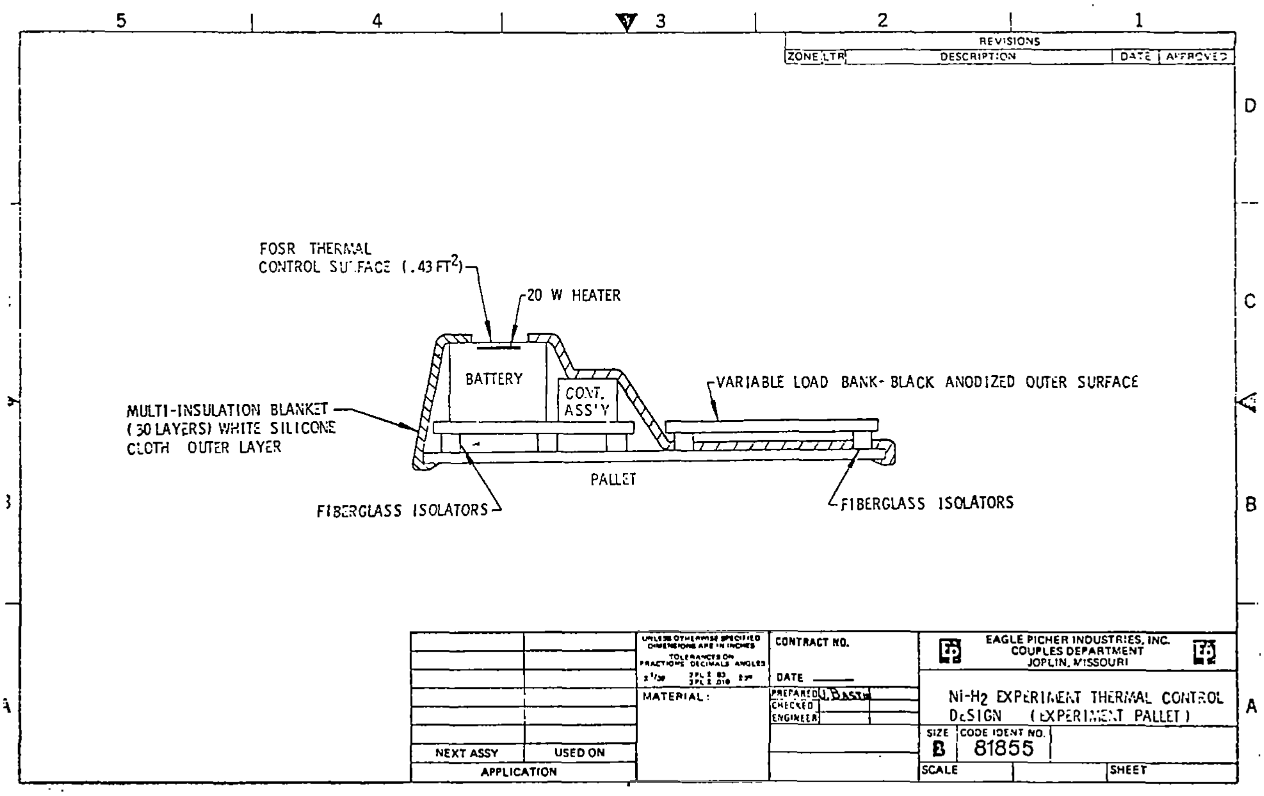

Figure 6-42

7% DOD (1,733 CYCLES) 4.6 A RATE:

TYPICAL DISCHARGE VOLTAGE CYCLE - 30.4 V TO 29.0 V

TYPICAL DISCHARGE TEMPERATURE CYCLE - 42°F TO 46°F

TYPICAL DISCHARGE PRESSURE CYCLE - 495 PSIG TO 470 PSIG

50% DOD CYCLE (26 CYCLES) 5.0 A RATE:

TYPICAL DISCHARGE VOLTAGE CYCLE - 30.6 V TO 27.4 V

TYPICAL DISCHARGE TEMPERATURE CYCLE - 42°F TO 48°F

TYPICAL DISCHARGE PRESSURE CYCLE - 495 PSIG TO 270 PSIG

100% DOD CYCLE (6 CYCLES):

DISCHARGE RATE	MID-POINT DISCHARGE VOLTAGE	PREDICTED CAPACITY (PRESS)	MEASURED CAPACITY
10 A	26.4 V	47.7 AHR	47.8 AHR
20 A	26.2 V	44.2 AHR	44.5 AHR
40 A	25.0 V	43.3 AHR	42.5 AHR
75 A	23.0 V	40.9 AHR	34.9 AHR

100% DOD CYCLE, THERMAL GRADIENTS:

20 A DISCHARGE RATE -	INSIDE CELL (MAX)	71.3°F
	OUTSIDE BATTERY (MAX)	67.3°F
	GRADIENT	4.0°F
40 A DISCHARGE RATE -	INSIDE CELL (MAX)	81.5°F
	OUTSIDE BATTERY (MAX)	73.1°F
	GRADIENT	8.4°F
75 A DISCHARGE RATE -	INSIDE CELL (MAX)	85.6°F
	OUTSIDE BATTERY (MAX)	75.2°F
	GRADIENT	10.0°F

FIG. 8 - SPACE EXPERIMENT DATA SUMMARY

Figure 6-43